METHOD AND SYSTEM FOR SURFACE OR CROSS-SECTIONAL PROCESSING AND OBSERVATION

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a method of surface or cross-sectional processing and observation and a system which the method is applied to.

In recent years, various types of devices including semiconductor devices and display devices have been becoming finer and more complicated in their structure in order to achieve improvements in functions. In particular, the elements and interconnections constituting each of such devices are of thin film forms having a thickness of the order of several atomic layers and stacked into a lamination structure. Accordingly, the demand for observation of the lamination structure has been great.

Therefore, the invention was made for the purpose of contributing to the evolution of devices in research and development, production process management, failure analysis, etc. through formation of at least one processed portion for observation of a surface or cross-sectional structure in a desired area in a sample surface and observation of the surface or cross section so formed.

DESCRIPTION OF THE RELATED ART

As a first technique, there is known a method of forming a cross-sectional structure exposed portion in a desired area in a sample surface with a focused ion beam to observe the exposed surface or cross sectional portion through a scanning ion microscope image by a focused ion beam or a scanning electron microscope(SEM) image by electron beam scanning (see JP-A-2-123749, p. 2 to 3, Fig. 2, for example).

As a second technique, there is known a method of etching a desired area in a sample surface with a focused ion beam to take out a sample chip and to observe the sample chip with a transmission electron microscope(TEM) (see JP-A-2002-148162, p. 2, Fig. 3, for example).

The first conventional technique has presented a problem of an insufficient resolution for observation in observing a surface or cross-sectional structure of a sample using a scanning ion beam microscope image or SEM image. In regard to the spatial resolution of SEM images, a spacial resolution much like one(1) nanometer is known to be the best performance that can be achieved by SEMs. However, the resolution is insufficient to manage a film thickness because a thickness of the thinnest one of film structures forming a sample is of the order of one(1) nanometer.

According to the second conventional technique, a TEM image is used for cross-sectional observation of samples.

Transmission electron microscopes have sufficient spatial resolutions because they enable observation of atoms forming a film structure. However, there has been a problem such that it is impossible to increase the throughput of the entire process because the second technique follows the procedure: preparing a sample chip for TEM observation using a focused ion beam system; and observing the prepared sample chip with a TEM.

Moreover, both the first and second conventional technique could only offer the information on sample geometry without electrical and mechanical characteristics of the sample.

SUMMARY OF THE INVENTION

The invention was made in order to solve the above problems.

The invention provides a method of surface or cross-sectional processing and observation including: a step of carrying out an etching process by irradiating a desired area in a surface of a sample with a focused energy beam while scanning the area, thereby to expose a predetermined layer's surface or cross-sectional structure of the sample; and a step of observing the exposed surface or cross section with a scanning probe microscope(SPM). In this method, a focused ion beam, an inert particle beam, a laser beam, etc. may be used

as the focused energy beam. Also, the invention provides a system for surface or cross-sectional processing and observation including: a focused energy beam irradiating unit for making a hole in a desired area in a sample surface; and a scanning probe microscope unit for observing a side wall of the hole formed by the focused energy beam irradiating unit. The unit for making a hole may be an inert particle beam irradiating unit, a laser beam irradiating unit, or a cutting unit for cutting a sample surface with a diamond needle other than a focused ion beam irradiating unit.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A-1D are views of assistance in explaining a method of surface or cross-sectional processing and observation according to the invention; and

Fig. 2 is an illustration of a system for surface or cross-sectional processing and observation according to the invention.

DISCRIPTION OF THE PREFERRED EMBODIMENTS

Now, a method according to the invention will be described in reference to Figs. 1A-1D.

As shown in Fig. 1A, a predetermined area 13 of a sample 12 is irradiated with a focused energy beam 11 to make a hole in the sample 12 with the area 13 set as an etching-target

region.

Subsequently, the exposed surface or cross-sectional surface is etched, as shown in Fig. 1B. The etching may be carried out, for example, by irradiating the exposed surface or cross-sectional surface with an argon (Ar) ion beam 14 at a remarkably shallow angle to the surface. Alternatively, an etching gas may be blown against the surface. By doing this, a damaged layer, which remains in the surface or cross-sectional surface after sputter etching by focused energy beam irradiation, is removed as an etching-target region 15. After mirror-like finishing, a stepped portion 16 may be formed in the resulting surface according to the difference in material among stacked layers as shown in Fig. 1C, in which the difference in etching rate among the materials is utilized. Alternatively, a reentrant and a protrusion may be made according to the materials of layered structures utilizing the difference in etching rate to the reactive gas among the materials in the case of using an etching gas.

Then, as shown in Fig. 1D, the resulting surface or cross sectional surface is observed by causing a probe 17 of a scanning probe microscope(SPM) to scan the surface.

Now, a system according to the invention will be described in reference to Fig. 2.

The system has: a focused ion beam irradiating unit 1 for focusing an ion beam and irradiating a sample surface with

the focused beam while scanning the surface; and an electron beam irradiating unit 2 for focusing an electron beam and irradiating an area identical to the focused ion beam-irradiated region in the sample surface with the focused beam while scanning the area, which are mounted on a vacuum chamber 3. The inside of the vacuum chamber 3 is kept in a vacuum condition by a vacuum pump 4. Also, the system has a sample table (not shown) in the vacuum chamber 3, on which a sample is placed. The sample table is provided with a multi-axial sample stage 5 for adjusting a tilt in X, Y and Z axial directions. Moreover, the vacuum chamber 3 is mounted with a SPM 6. The microscope 6 enables the observation of a beam-irradiated region of a sample surface irradiated by the focused ion beam irradiating unit or electron beam irradiating unit and the observation of a surface or cross section of the sample formed by the focused ion beam irradiating unit. A bias voltage source is connected between a probe of the SPM and the processed sample so that a voltage can be applied between the probe and the processed sample. The system further includes a micro-ampere meter for detecting a current flowing through the probe or the processed sample. Further, these are managed by a computer system 7.

The vacuum chamber 3 is opened to an atmospheric pressure to load a sample onto the sample stage 5. The sample stage 5 is operated so that a processed region in the sample surface

coincides with a focused ion beam-irradiated region. Then, the processed region in the sample surface is irradiated with a focused ion beam by the focused ion beam irradiating unit 1 while undergoing the scan. Secondary charged particles generated by irradiating the sample surface with the ion beam are detected by a detector for secondary charged particles (not shown), which is mounted in the vacuum chamber 3, thereby to observe a scanning ion microscope image of the sample surface. Based on the scanning ion microscope image, an area where a surface or cross section is to be formed is determined. By irradiating the determined area with a focused ion beam while scanning the area, a surface or cross section where the lamination structure of the sample is exposed is formed.

Subsequently, the exposed surface or cross-sectional portion is irradiated with an Ar ion beam by an Ar ion beam irradiating unit (not shown) at a shallow incident angle to the exposed surface or cross-sectional portion to etch the top face of the exposed portion away. A damaged portion remaining in the surface or cross-sectional portion after the irradiation by the focused ion beam is thus removed.

Afterward, the resulting surface or cross-sectional portion is observed with the SPM unit 6. Although there have been known multifarious principles and observational method techniques as in a scanning tunneling microscope (STM) and an atomic force microscope (AFM) in regard to SPMs, a SPM with

an optimal measurement mode can be selected as the microscope unit 6 so as to suit the materials and film thickness of stacked layers, observational purposes, etc.

Now, electromagnetic and mechanical measurements, and geometrical measurements with high resolution will be described below.

First, examples of electromagnetic measurement with respect to a target sample plane will be described. In the case of measuring dopant concentrations or dielectric constants, the steps below are followed: to dispose a highly sensitive capacitance detector in proximity to a probe; to apply an alternating current (AC) from the bias voltage source to a sample; detect a change in capacitance just under the probe synchronously; and to calculate the dopant concentration or dielectric constant of the sample based on the detected change of the capacitance. Further, in the case of measuring a target sample plane or cross section in electrical conductivity, the steps below are followed: to place a conducting probe in contact with a portion to be measured; to scan a voltage according to a bias voltage source; to detect a current flowing at that time with the micro-ampere meter described above; and to determine an I/V curve at the contact point. Alternatively, the probe may be made to scan the portion to be measured with the bias voltage kept constant, thereby to carry out current image mapping. In the case of measuring a target sample plane or

cross section in potential,, the steps below are followed: to apply an AC voltage to the sample face; to control the voltage of the bias voltage source so that the amplitude of a cantilever oscillating according to the frequency of the AC electric field reaches zero; and to measure a surface potential of the sample based on the control voltage. Finally, in the case of using a magnetic-force microscope, a magnetic probe is used to determine a magnetic domain where the magnetic leakage appears within the surface or cross section.

Second, examples of measurement of mechanical properties with respect to a target sample plane will be described. The information on friction in a sample plane is measured by a friction force microscope. The difference in friction force among the materials, which are arranged to form a mutilayered structure in the cross section thereof, provides contrast for the substances of the stacked layers in the cross section, and as such, the film thicknesses of the stacked layers can be measured. Also, the difference in friction force arising in the target surface enables the detection of contaminations, etc. in stacked materials. Now, in regard to the information on the hardness of a target sample plane, the probe is brought into contact with the sample face to provide it with infinitesimal vibrations, the difference in vibrational phase between the power supply that provides the infinitesimal vibrations and the probe provides the hardness information of

the sample face.

Third, high resolution measurements using a SPM will be described.

It is assumed here that the thickness of a multilayered sample of a cross section has been reduced to about 1 to 2nm. In order to measure the cross section with high resolution, a low-energy-accelerated Ar ion beam is radiated in etching a portion of the cross section to remove a damaged layer damaged by the ion beam processing. Finally, the target plane is finished into a mirror-like condition. An etching gas may be further blown against the cross-sectional portion. During this time, an electron beam may be radiated by the electron beam irradiating unit 2 in parallel with the blowing of the etching gas. Thus, the cross sectional portion can be finished into a mirror-like condition simultaneously with the removal of a damaged portion in the cross section. Further, because the selective etching based on the difference in material between stacked layers, which construct a cross section, produces a micro-scale stepped portion in the cross-sectional portion, the measurement of the stepped portion with a high resolution SPM enables the high resolution imaging of a multilayered structure of the cross section at sub- nanometer scale.